https://doi.org/10.1051/epjconf/202636205001

Remote Detection and Identification of Plastics with Raman Lidar

T. Somekawa[a,b], S. Matsuda[a], S. Kurahashi[a], A. Yogo[b], and H. Kuze[c]
[a] *Institute for Laser Technology, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan*
[b] *Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan*
[c] *Center for Environmental Remote Sensing (CEReS), Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, Japan 263-8522*
somekawat@ilt.or.jp

Abstract: We report a portable Raman lidar system that can remotely detect ocean plastics. The system is based on a frequency-doubled, Q-switched Nd:YAG laser operated at 532 nm with a receiver telescope equipped with a gated ICCD spectrometer. Stand-off detection of plastics is achieved at 6 m away, thus providing the groundwork for better solutions in monitoring ocean plastic pollution.

1. Introduction

Plastic pollution in the ocean has been identified as a threat to marine ecosystems. Assessing the particle size, concentration, and distribution of floating or suspended plastic debris in the ocean is a prerequisite for managing and protecting marine ecosystems. The traditional in situ sampling laboratory-based methods, such as infrared and Raman spectroscopic techniques, are precise and accurate [1, 2]. However, they are constrained by time-consuming manual sampling and high sampling cost: as a result, the insufficient availability of field sampling data limits our understanding of its effect on the marine environment.

Remote sensing, which has high temporal and spatial resolution, would provide an excellent ancillary tool to explore the distributions of plastic debris quantitatively. As a commonly used detection technology based on optics, fluorescence and short-wave infrared absorption techniques are employed for plastic detection [3, 4]. However, the complete identification of the material is difficult due to the broad emission band of fluorescence spectra and the broad absorption features found in infrared reflectance spectra. Therefore, here we propose a new Raman spectroscopic technique that realizes remote detection with selectivity higher than the conventional fluorescence and absorption techniques [5-8].

This paper reports a compact Raman lidar system recently developed for remote plastic detection. The diagnosis of plastic targets is demonstrated at a maximum stand-off distance of 6 m. The remote detection capability of our method is highly promising for monitoring floating or suspended plastic debris in the ocean.

2. Experiment

A schematic diagram of the Raman spectroscopy is shown in Fig. 1(a). The laser source is a frequency-doubled Nd:YAG laser emitting green light at 532 nm. The laser was operated with a pulse width of about 5 ns at full width at half maximum (FWHM) and a repetition rate of 20 Hz. The maximum pulse energy was about 180 mJ. We selected the laser wavelength of 532 nm to minimize the effect of background fluorescence from plastic samples.

The Raman signal from plastic samples such as polyethylene foam, a plastic bag (polyethylene), and polystyrene foam are collected using an achromatic lens. After passing through the edge filter at 532 nm, the Raman signal is coupled into an optical fiber bundle by using an achromatic lens. The collected Raman signal was delivered to a spectrometer (Acton, SpectraPro-2300i) equipped with a thermoelectrically cooled CCD camera (Princeton Instruments, PIXIS 400).

In the lidar application, as shown in Fig. 1(b), the plastic sample was located 6 m away from the last sending mirror of our Raman lidar system. The Raman scattering was collected by a 127 mm diameter Schmidt-Cassegrain telescope and focused through an edge filter at 532 nm to a fiber-coupled spectrograph equipped with an ICCD camera (Princeton Instruments PI-MAX4). We chose the co-axial setup since the scheme is beneficial for short-range object detection. We adjusted the overlap of the lidar system by aligning the last mirror.

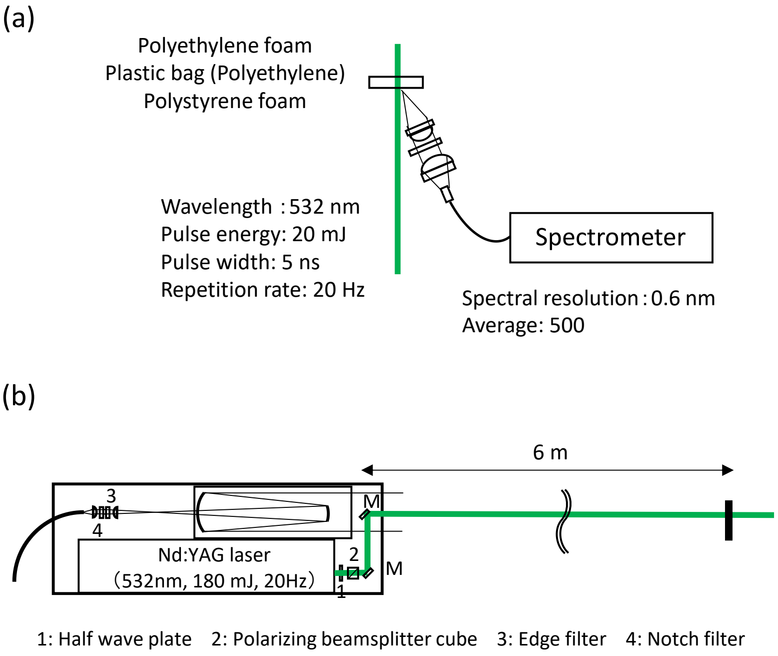

Figure 1. Schematic diagrams of experimental setup: (a) Raman spectroscopy and (b) Raman lidar.

3. Results and discussion

Figure 2 shows Raman spectra of polyethylene foam, a plastic bag (polyethylene), and polystyrene foam. These Raman spectra were offset vertically for better visualization. The accumulation number of the spectrometer was set to 500, and it was repeated five times in each case.

Raman spectra of polyethylene foam and the polyethylene bag show the same spectral features. The band at 1294 cm^{-1} represents the twisting mode of the CH_2 groups. The broad band at 1442 cm^{-1} is a mixture of bending modes of CH_2 bonds and groups. The bands at 2848 and 2881 cm^{-1} correspond to the symmetric and asymmetric stretching vibration modes of the CH_2 groups, respectively [2].

Raman spectrum of polystyrene foam shows an intense band at 3058 cm^{-1}, arising from the stretching of C-H bonds on the benzene ring. The bands at 1454 and 1604 cm^{-1} are the CH_2 scissoring and ring (skeletal) modes, respectively. The bands at 2856 and 2909 cm^{-1} belong to aliphatic stretching modes of symmetric and antisymmetric types, respectively [2].

Figure 3 shows typical remote Raman spectra of the polyethylene foam at a remote distance of 6 m. The recorded spectrum was collected from 1600 laser shots with an ICCD gate width of 5 ns with an ICCD gain of 100.

From this data presented, we can detect the Raman spectrum of polyethylene at 6 m away and discriminate the type of plastics from Raman signals.

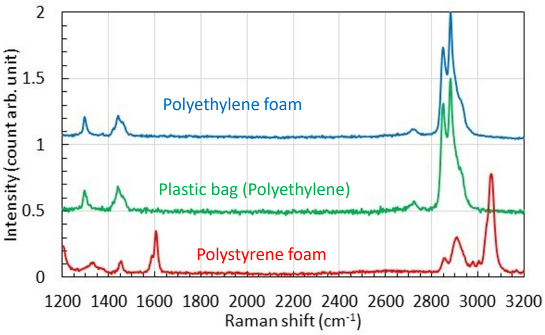

Figure 2. Raman spectra of polyethylene foam, a plastic bag (polyethylene), and polystyrene foam.

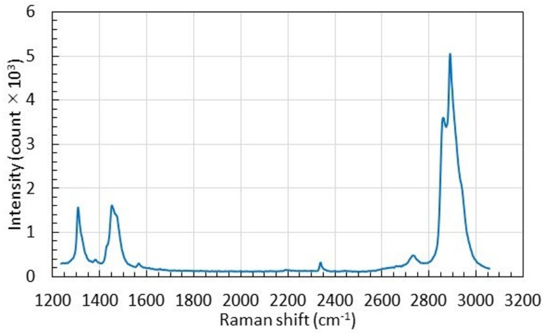

Figure 3. Raman spectrum of polyethylene foam located 6 m away in the air.

4. Conclusions

In our laboratory experiment, we have investigated the feasibility of Raman lidar for ocean plastics detection. In the future, various standard plastic samples will be analyzed for classification by using the supervised learning technique, leading to improved classification and identification under in situ condition.

Acknowledgment

This work was supported by JSPS KAKENHI (grant number JP22H03756).

References

[1] W. Cowger, A. Gray, H. Christiansen, H. DeFrond, A. D. Deshpande, L. Hemabessiere, E. Lee, L. Mill, K. Munno, B. E. Ossmann, M. Pittroff, C. Rochman, G. Sarau, S. Tarby, and S. Primpke, "Critical review of processing and classification techniques for image and spectra in microplastic research," Appl. Spectrosc. **74**, 989-1010 (2020).

[2] V. Nava, M. L. Frezzotti, and B. Leoni, "Raman spectroscopy for the analysis of microplastics in aquatic systems," Appl. Spectrosc. **75**, 1341-1357 (2021).

[3] L. Palombi and V. Raimonde, "Experimental tests for fluorescence LIDAR remote sensing of submerged plastic marine litter," Remote Sens. **14**, 5914 (2022).

[4] S. P. Garaba and H. M. Dierssen, "An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics," Remote Sens. Environ. **205**, 224-235 (2018).

[5] T. Somekawa, A.Tani and M. Fujita, "Remote detection and identification of dissolved CO_2 using a Raman lidar system," Appl. Phys. Express, **4**, 112401 (2011).

[6] T. Somekawa, J. Izawa, M. Fujita, J. Kawanaka, and H. Kuze, "Remote detection of oils in water using laser Raman spectroscopy," Opt. Commun. **480**, 126508 (2021).

[7] T. Somekawa, J. Izawa, M. Fujita, J. Kawanaka, and H. Kuze, "Raman lidar for remote sensing of oil in water," Appl. Opt. **60**, 7772-7774 (2021).

[8] T. Somekawa, S. Kurahashi, S. Matsuda, A. Yogo, and H. Kuze, "Remote visualization of underwater oil using a flash Raman lidar system," Opt. Lett. **48**, 5340-5342 (2023).